Compte rendu LISA: AIV/T

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This Compte rendu is based on various reflections meetings between :

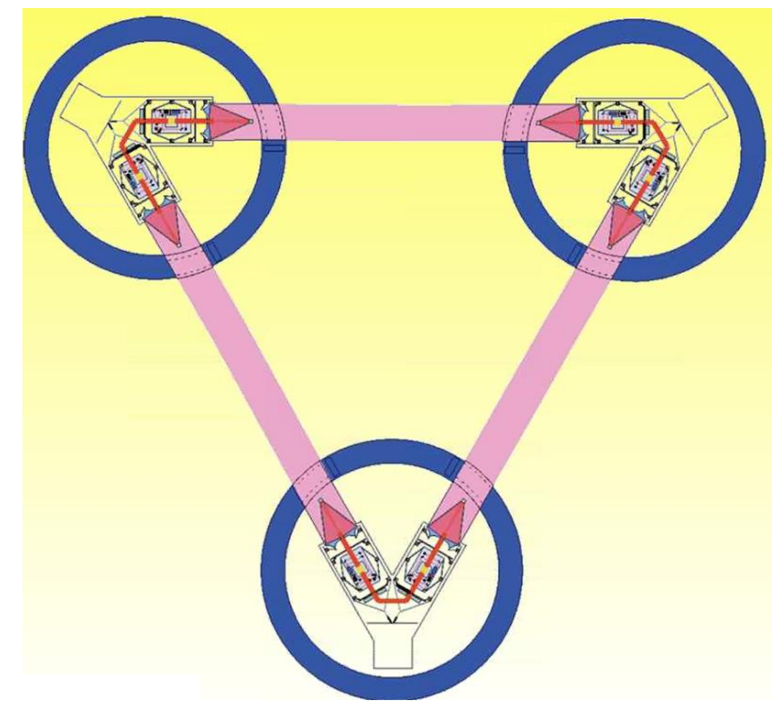
- APC, ARTEMIS and PASO/CNES (France)
- Payload Coordination Team (PCT) (ESA/ESTEC)
  - H. Halloin & N. Dinu Jaeger members, in charge of AIV/T aspects

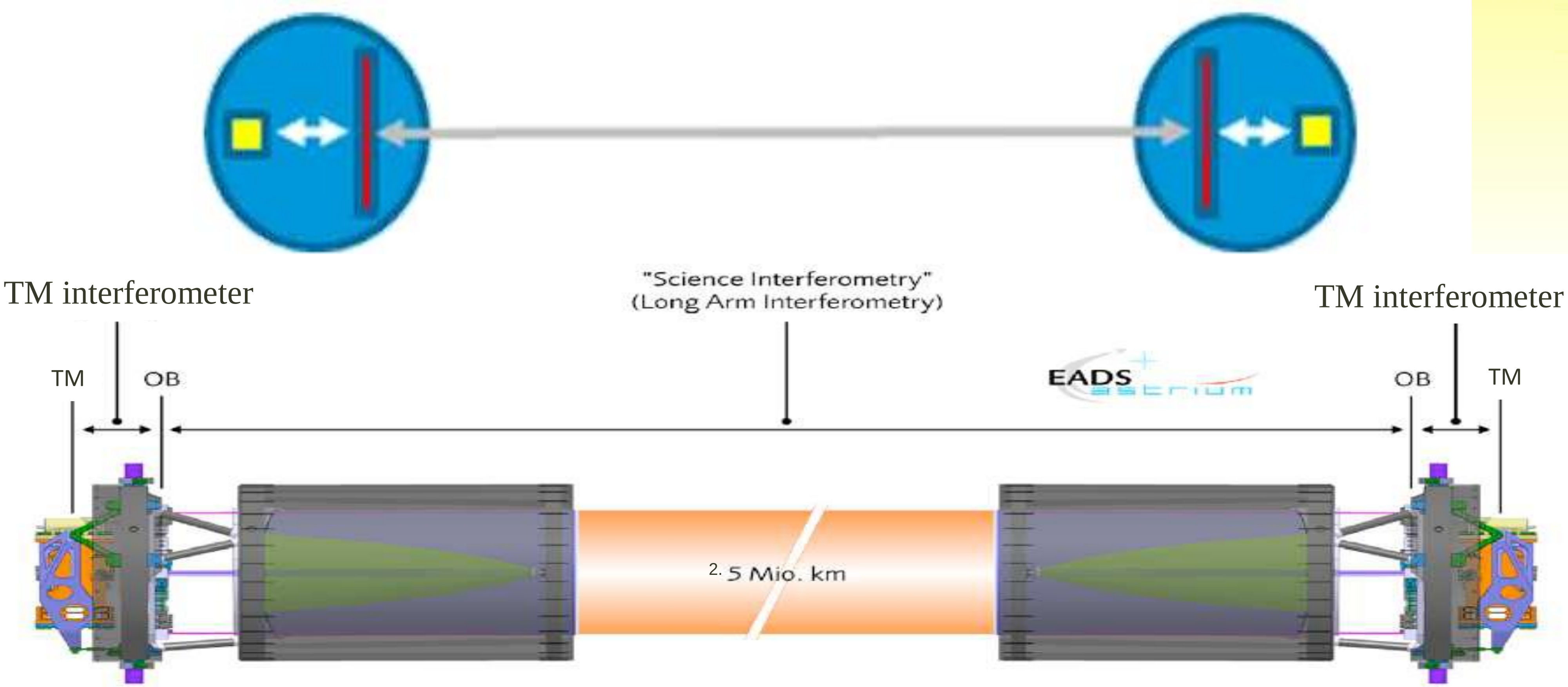
Outline

- State-of-the-art of LISA payload subsystems
- Status of actual reflections on AIV/T activities
- Short and long term AIV/T activities

LISA mission goals

- The goal of the mission is to detect Gravitational Waves (GW) at low frequencies
  - range from 10^{-5} Hz to 0.1 Hz
- Laser heterodyne interferometry used to detect minute distance variations between free flying Test Masses (TM)
- Spacecraft (S/C) required to “shield” the TM from external perturbations (drag free control), internal perturbations to be minimized (EMC, mass balance, thermal …)
- Three arms required to determine origin and polarization (redundancy)
- Each arm measurement broken into three legs:

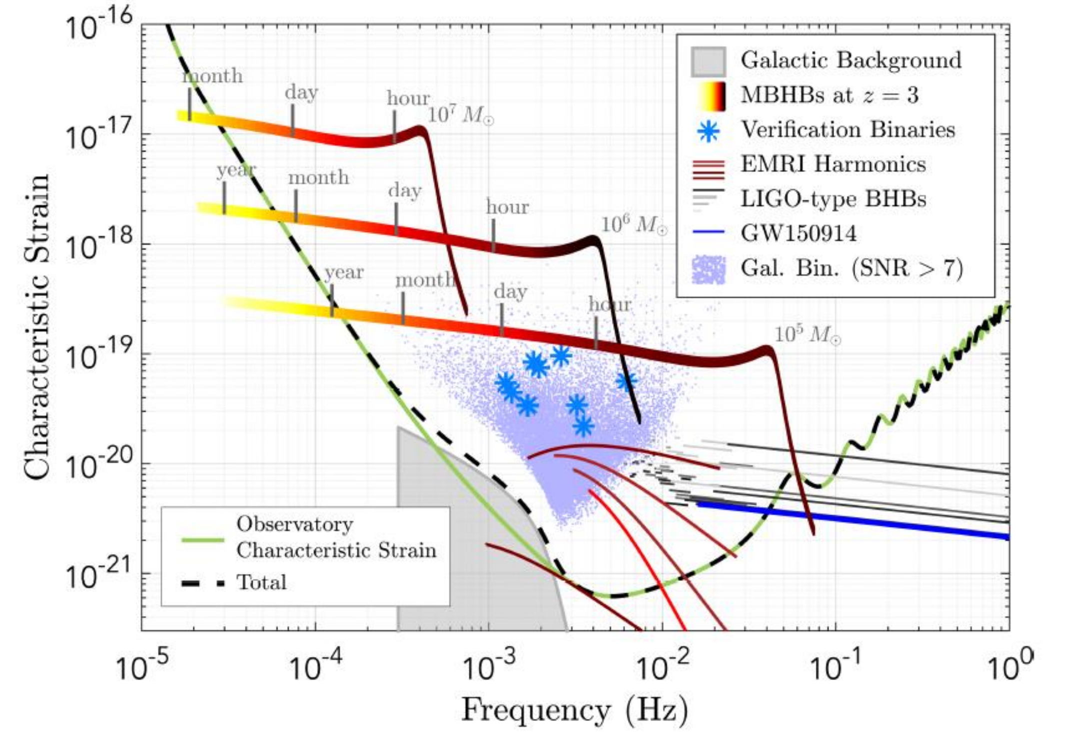




Measurements to be performed are in the picometer range (1 pm = 10^{-12} m)

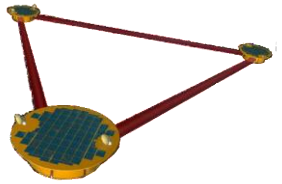
LISA sensitivity and performance requirement

- Sensitivity curve for LISA 3-arm configuration



- LISA top key parameters performance requirements:

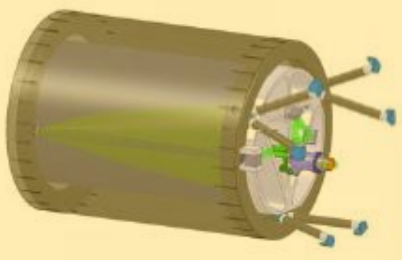
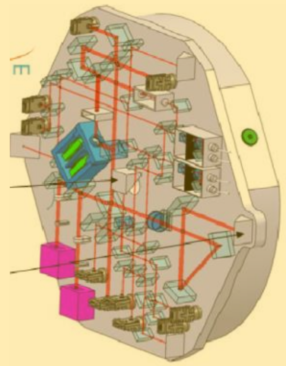
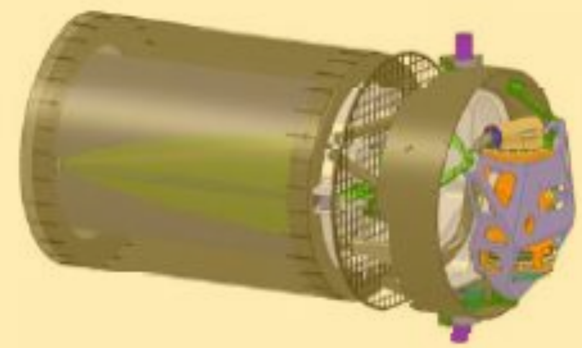
1. Stray acceleration of TM
   - $S_a^{1/2} \leq 3 \cdot 10^{-15} \frac{m \cdot s^{-2}}{\sqrt{Hz}} \cdot \sqrt{1 + \left(\frac{0.4mHz}{f}\right)^2} \cdot \sqrt{1 + \left(\frac{f}{8mHz}\right)^4}$; 100 µHz ≤ f ≤ 0.1 Hz
   - Mostly applies to GRS that comprises the TM and the surrounding sensing and actuation hardware
2. Laser interferometer readout noise
   - $S_{IFO}^{1/2} \leq 10 \cdot 10^{-12} \frac{m}{\sqrt{Hz}} \cdot \sqrt{1 + \left(\frac{2mHz}{f}\right)^4}$; 100 µHz ≤ f ≤ 0.1 Hz
   - Mostly concerns the interferometric measurement system: telescope, optical bench, phase measurement system, laser, clock and TDI
3. Arm length response
   - Partial cancelation of the signal because GW period become shorter than the arm length
   - Achievable by optimization of:
     - GRS from LPF with two TM per S/C (46 mm cubic, 2 kg Au-Pt TM)
     - Armlength: 2.5 million km
     - Telescope with 30 cm diameter
     - Laser power: 2W end-of-life out of delivery fiber to the OB



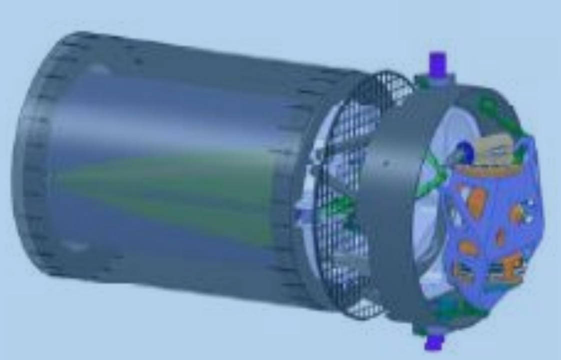
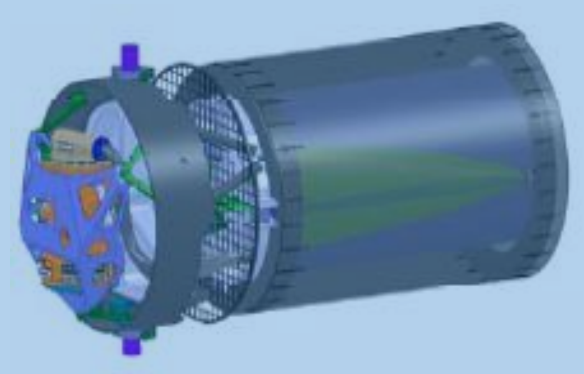
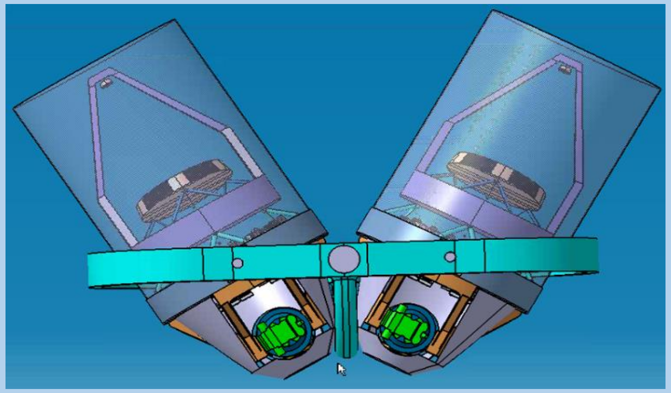
LISA Payload elements on each S/C

Telescope + Optical Bench + Grav.Ref. Sensor = Moving Optical SubAssembly

(T) (OB) (GRS) (MOSA)

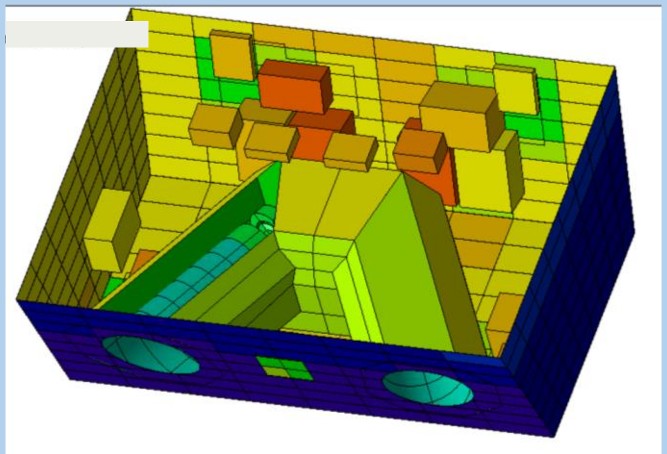
 +  +  = 

2x MOSA = LISA Core Assembly (LCA)

 +  = 

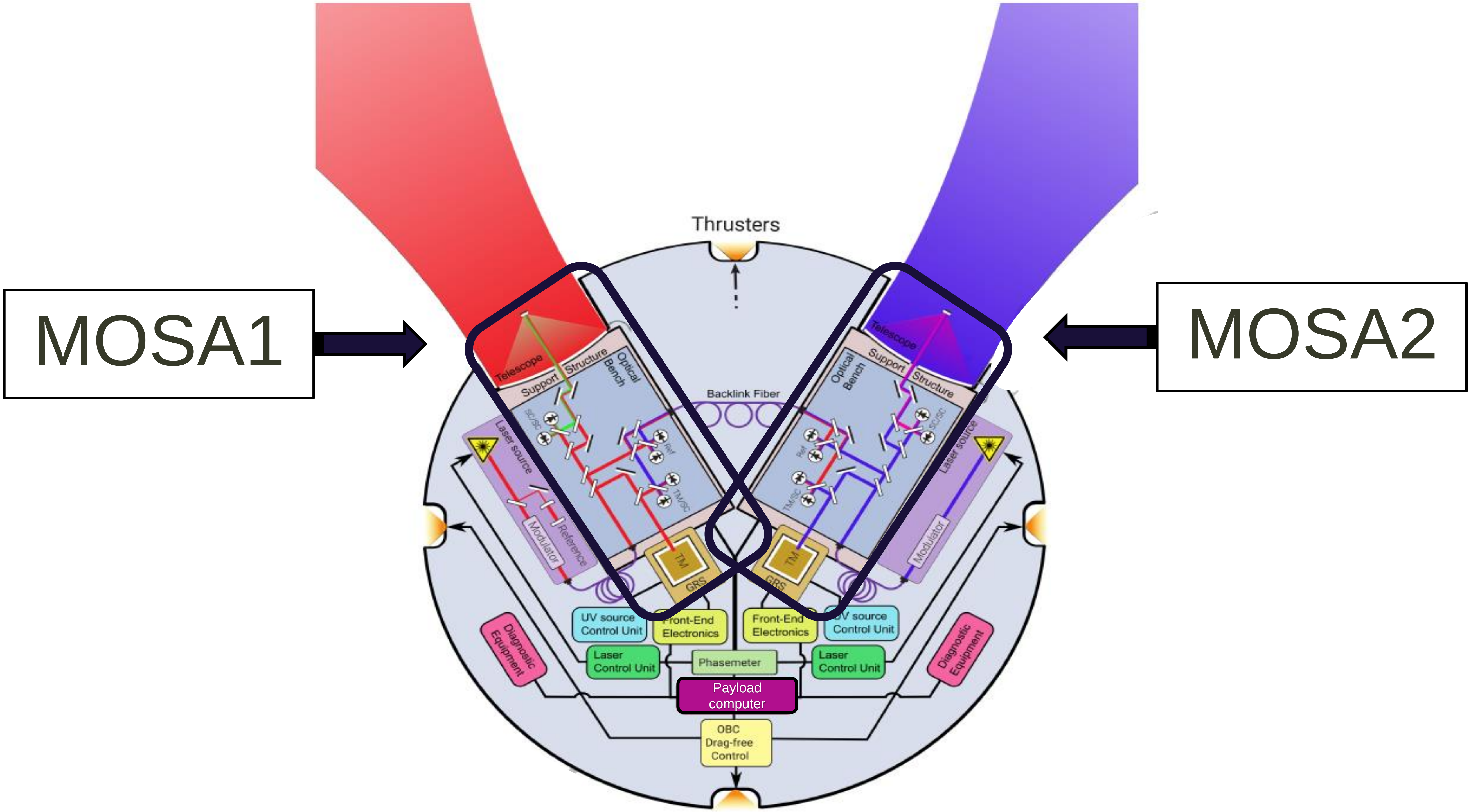
LCA + Electronics boxes = Payload

(Phasemeter, Laser Assembly, GRS FEE, Computers (on-board+payload), etc.)



EADS Astrium & CDF/ESTEC drawings

Detailed LISA payload elements on each S/C



MOSA = Moving Optical Sub-Assembly

- *Telescope (T) + Optical Bench (OB) + Gravitational Reference Sensor (GRS) mounted on a mechanical structure*
- *Additional subsystems (i.e. laser, phasemeter, diagnostics) are required for performance validation*

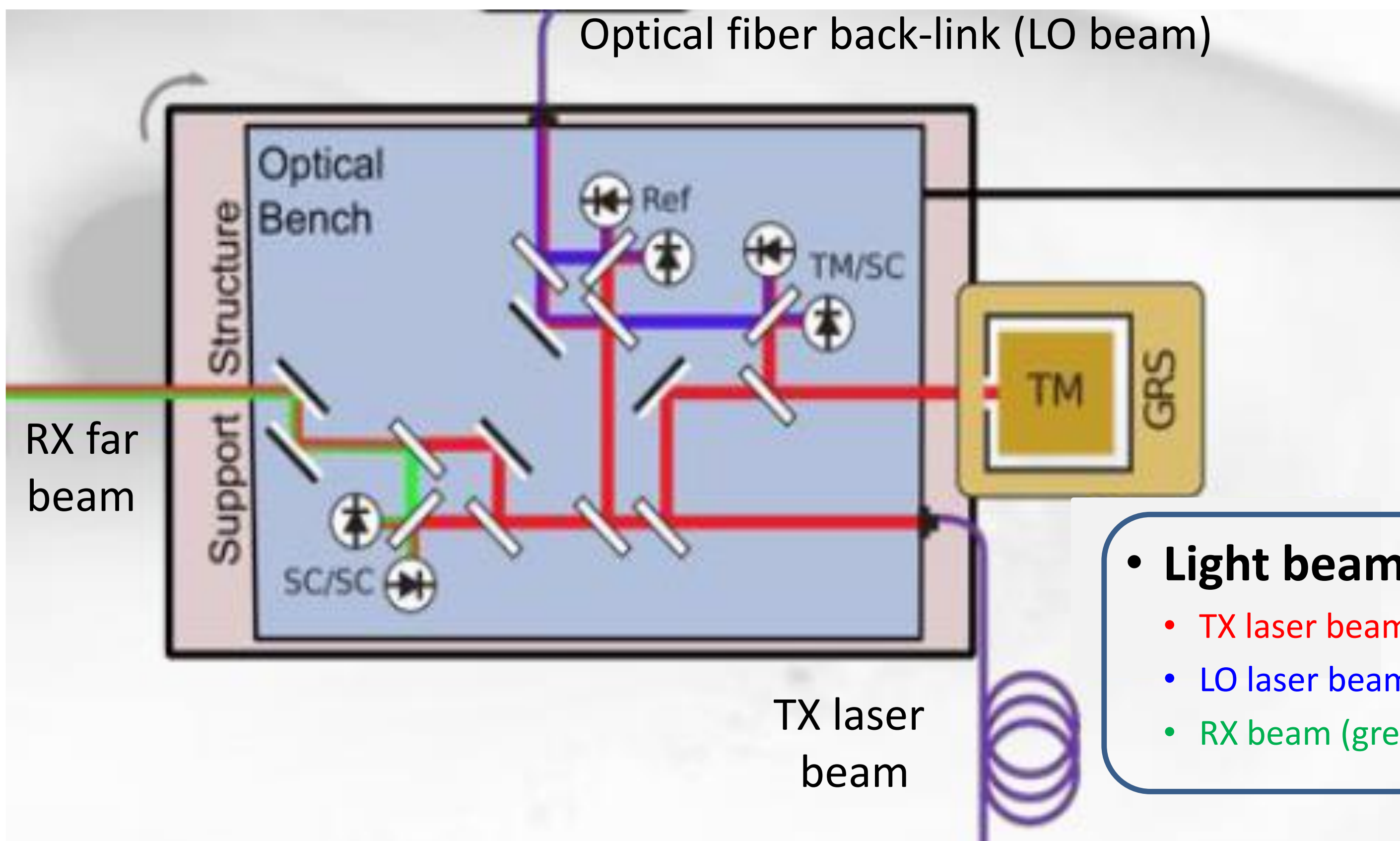
Optical Bench (UK)

• Main functionality

- Combine laser beams from telescope (far S/C, RX beam), local laser (original TX beam or reflected to TM) and adjacent OB (backlink fiber, LO beam) to allow three distinct interferences:
  - Inter-S/C interferometer (i.e. “science” interferometer (TX and RX))
  - Test-mass interferometer (TX reflected on TM and LO)
  - Reference interferometer (TX and LO)

• Concept design: double side

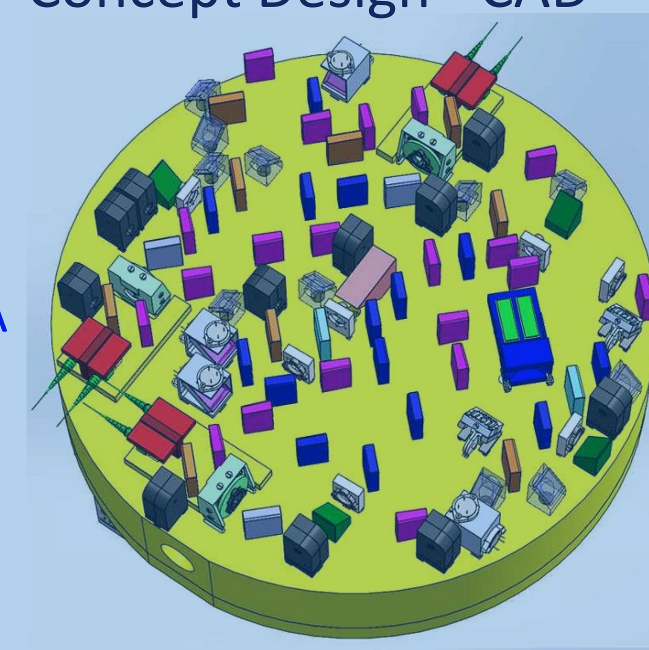
- A: contains all optical elements for interferometer measurements, opt. interfaces
- B: contains all interferometers read-outs



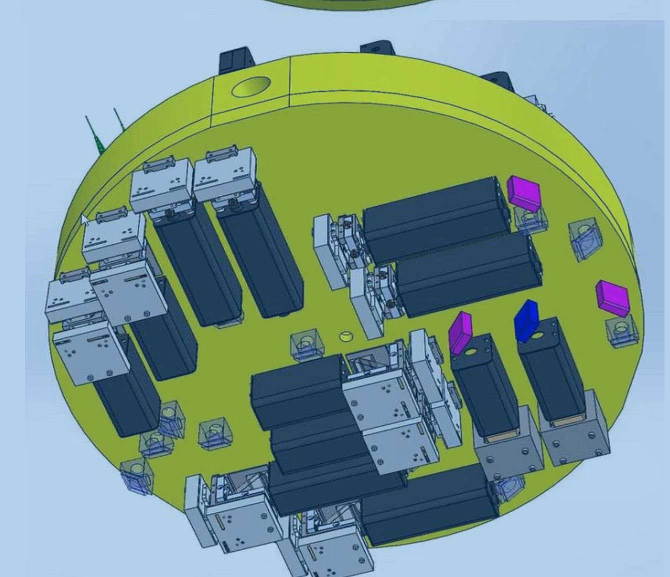
- **Light beams**
  - TX laser beam (red)
  - LO laser beam (blue)
  - RX beam (green)

Concept Design - CAD

Side-A



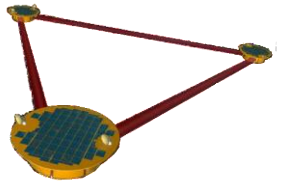
Side-B



Courtesy of E. Fitzimons (UK-ATC)

OB state-of-the-art

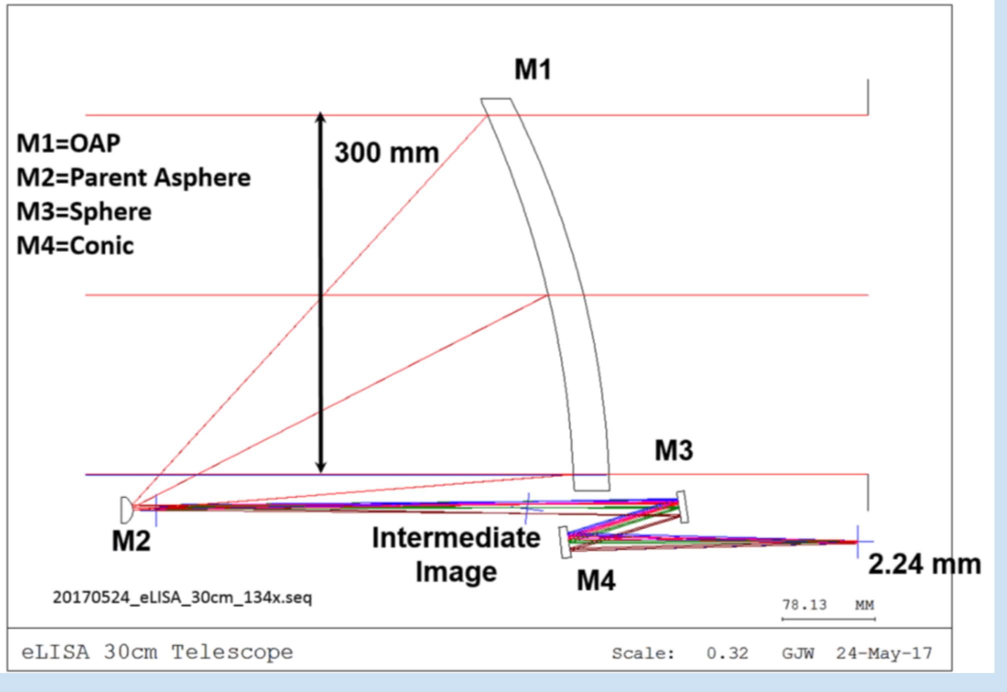
- *Bonding technology and ~10 µm alignment accuracy (LPF heritage, TRL9)*
- *Fiber injectors, automatic OB manufacturing, photoreceivers …(TRL 4-5)*



Telescope (NASA)

- Main functionality
  - Simultaneously transmit and receive beam light with efficient optical power transfer
    - High transmitted optical power: 1.26 W
    - Low received optical power: ~500 pW
- Concept design: Off-axis Cassegrain telescope (4 mirrors)
  - 300 mm diameter of primary mirror (M1)
  - 2.24 mm pupil diameter on optical bench
  - 134x magnification

Baseline design by NASA
(GSFC/ J. Livas)



Alternative design by ESA
(ITT TAS-I + TAS-F, ARTEMIS/OCA, APC, LMA)

Telescope state-of-the-art (TRL 4)

- design under development

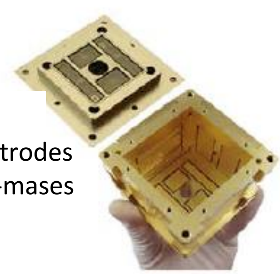
Gravitational Reference Sensor (Italy)

- **Main Functionalities**
  - Enable TM/SC control at roughly 2.5 nm/√Hz level and 200 nrad/√Hz level (using y, z, θ capacitive readouts)
  - Force actuation at nN / 10 pNm level (all degrees of freedom excepting x)
  - Shield the TM and limit stray forces, allowing TM to be at ~ 3 fm/s^2/√Hz level (GRS + payload + S/C)
  - Allow TM to be used as a mirror for <10 pm/√Hz IFO readout
- **Concept design**
  - TM + surrounding hardware (electrode housing, vacuum enclosure, caging mechanism, charge management) + electronics

Cube 46mm
1.96 kg
73/27% Au/Pt alloy
$\chi \leq 2 \times 10^{-5}$; Au coated
$\rho \sim 2 \times 10^4$ kg/m^3
Reduced effect of external forces on TM

Test Mass

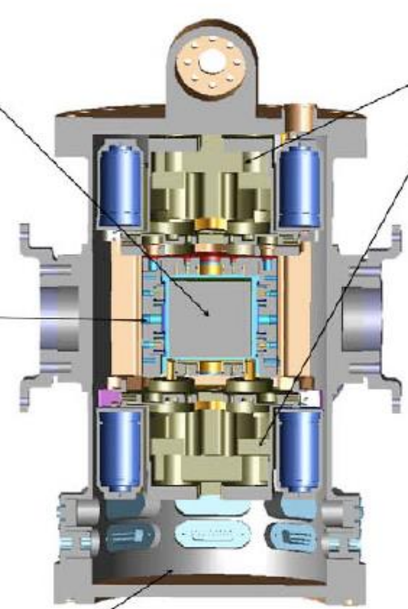
Mo cubical box
Au-coated sapphire electrodes
4 mm gap between test-mases and its surroundings



Electrode Housing

Ti vacuum vessel
P < 10^{-6} Pa
Getter pump

Vacuum Enclosure



Caging Mechanism

Prevent damage from launch vibrations
Test-masses:
- Caged with F~2000N during launch
- Released within 200 μm error box
- Residual velocity < 5×10^{-6} m/s

Charge Management

TM charging:
- charge particles created by interaction of cosmic rays with spacecraft materials
- charging rate: 50 e/s

Surface charge removal:
- UV light (254 nm)
- photoelectric effect

Front End Electronics

FEE acquires TM position data (sensing) from the electrodes housing and control TM position (actuation) through data from Drag Free Attitude Control System (DFACS)

Lisa Pathfinder GRS

GRS state-of-the-art (heritage LPF, TRL 9)

- *UV LED technology under development (US; TRL 4)*
- *Venting modification….*

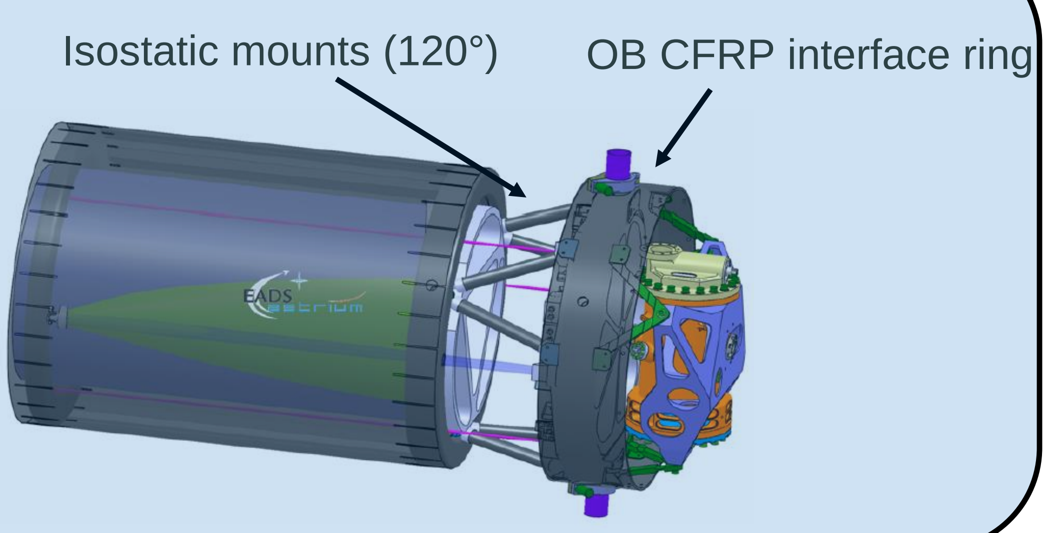
MOSA mounting structure (ESA/Prime?)

- Main Functionalities
  - Load taking device for three subsystems: T + OB + GRS
    - Telescope: mass ~ 9.3 kg; dimensions: length ~ 800 mm; height ~ 400 mm;
    - OB: mass ~ 17.5 kg; dimensions: ϕ ~ 450 mm x 200 mm;
    - GRS: mass ~ 19.7 kg; ϕ ~ 200 mm
  - Assure mechanical interface between T, OB and GRS
    - Isostatic interface with the OB, stable and minimizing OB distortion
    - Thermal balancing
      - OB ~ 20°C; Telescope: M2 ~ -80°C, M1 ~20°C
      - Optical path length stability between Telescope and OB at the few nm/√Hz level
  - Assure mechanical interface with LCA/SC mechanical structure
- Material characteristics
  - High stiffness, low mass, low distortion
  - Material of very low coefficient of thermal expansion (CTE)
- Concept design
  - Under development: ASTRIUM & NASA/GSFC proposals

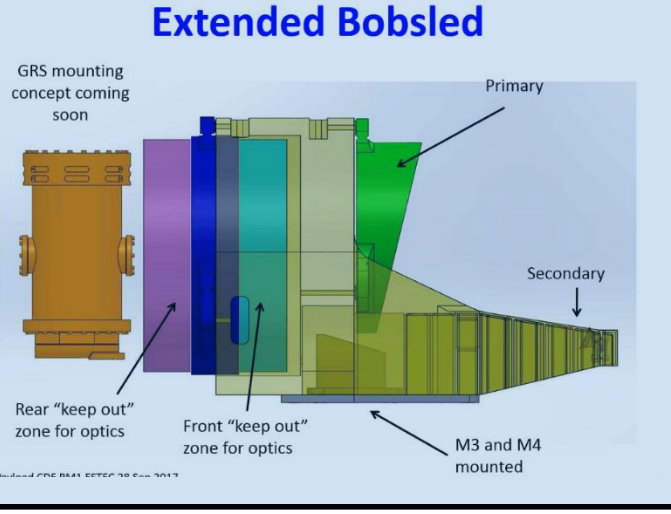
MOSA mounting structure state-of-the-art (TRL ?)

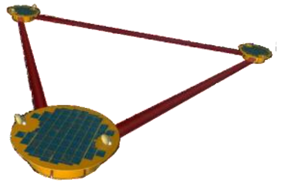
- *Under development*

EADS ASTRIUM design



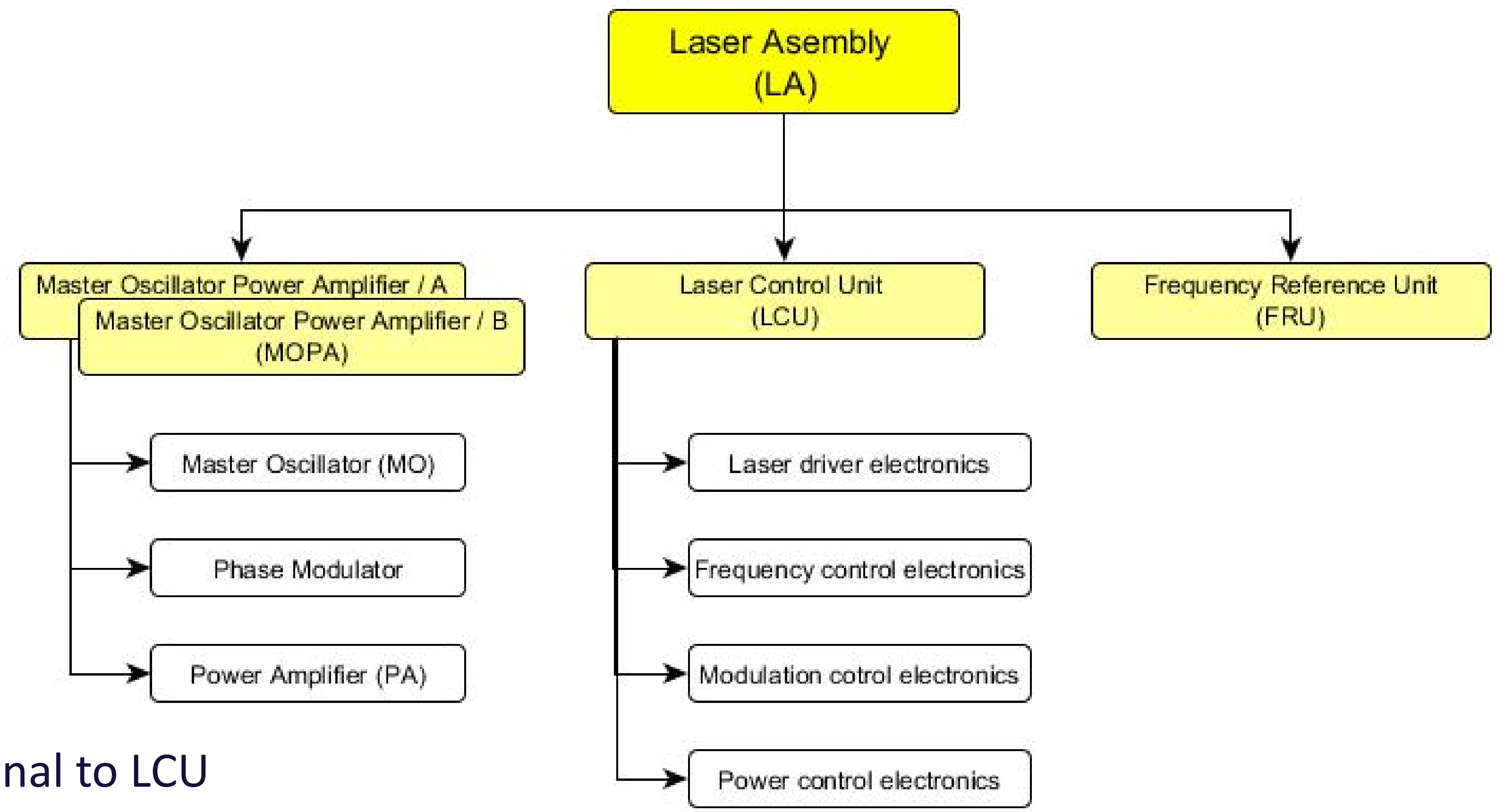
USA/GSFC design (Courtesy of J. Livas)





Laser Assembly (NASA)

- **Main functionality**
  - Deliver CW laser source
    - 1064 nm & 2W for laser interferometry
    - Frequency and amplitude stabilized
- **Concept design**
  - 2x Laser Assemblies (LA)/payload
    - Each LA is associated to one OB and points towards corresponding far S/C; it contains:
    - 2x Master Oscillator Power Amplifier (MOPA) for full redundancy
      - Master Oscillator (MO)
      - Phase modulator
      - Power Amplifier (PA)
    - 1x Laser Control Unit (LCU):
      - laser drive electronics
      - frequency control electronics
      - modulation control electronics
      - power control electronics
    - 1x Frequency Reference Unit
  - 1x Laser Pre-stabilization (LPS) subsystem
    - Self contained unit providing feedback signal to LCU
    - Frequency stabilization of MOPA lasers

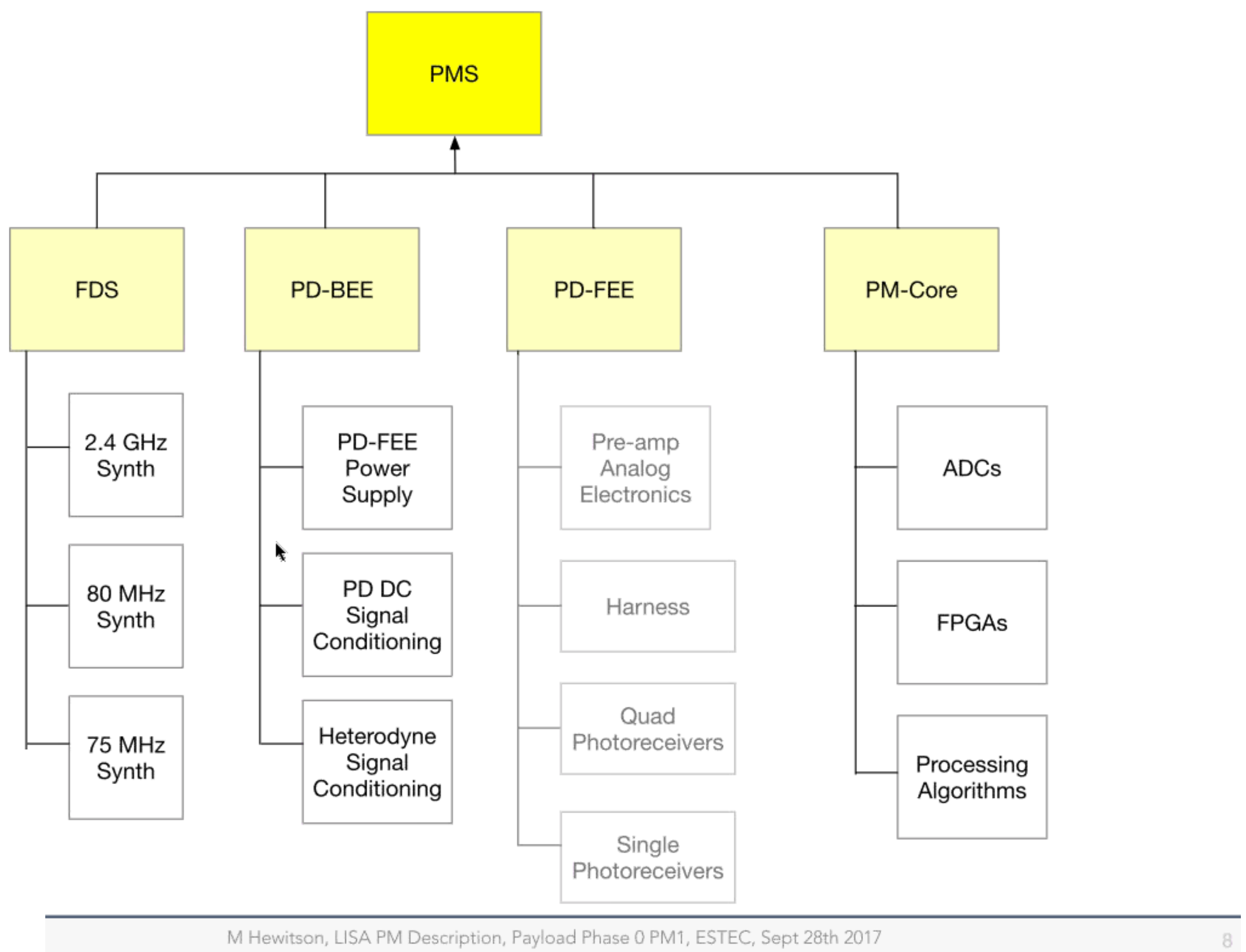


Laser state-of-the-art

- *Fiber Amplifier & Master oscillator (ELC type): TRL 4*
- *Frequency Reference Unit: TRL 8 (Grace-FO heritage)*

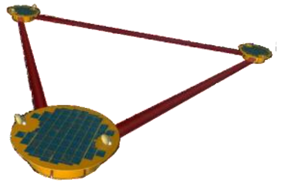
Phasemeter (Germany)

- **Functionalities**
  - Delivers primary measurements of the mission
    - Longitudinal measurements for inter-S/C, TM, and reference IFO
    - Attitude measurements using differential wavefront sensing
      - S/C w.r.t. incoming wavefront
      - TM w.r.t. local S/C
    - These are phases: conversion to length/angle may be done elsewhere (payload processing)
  - Auxiliary functions
    - Pseudo random code for ranging
    - Data transfer over optical link
    - Clock noise transfer
    - Pilot tone
- **Concept design**
  - Frequency Distribution System (FDS)
  - Photodiodes Back-end Electronics (PD-BEE)
  - PM core: ADCs, FPGA, Processing algorithm



PM state-of-the-art

- *Core functionality: TRL 8, Grace-FO heritage*
- *LISA specific functions (clock transfer, jitter calibration etc.): TRL 4*
- *To be determined: nr. of channels, exact bandwidth…*



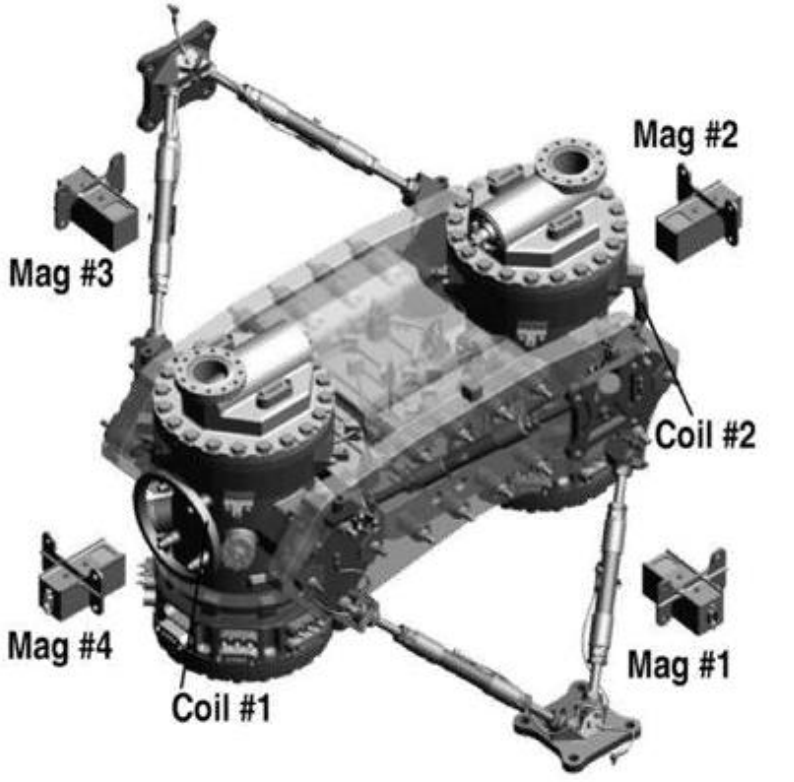
Diagnostics (Spain)

• Main functionality

- Monitor disturbances perturbing either test mass geodesic motion or metrology subsystem
  - Radiation monitor
  - Magnetic diagnostics
  - Temperature diagnostics

• Concept design

- Magnetic diagnostics
  - Fluxgate magnetometers outside of thermal shield (LPF heritage)
  - Alternative solution: Anisotropic magneto-resistors (AMR)
    - compact, avoiding effects of back actions
- Temperature diagnostics
  - Telescope
    - T stability requirement: 100 nK/√Hz
    - 7 T sensors (3 near M1, 2 near M2, 2 near M3/M4)
    - Possible heaters? (to keep the telescope close to room T)
  - Optical Bench
    - T stability requirement: 100 nK/√Hz
    - ~15 sensors, at hot spots locations (ex: PDs, Constellation Acquisition Sensor etc)
  - GRS
    - T stability requirement: 10 µK/√Hz
    - T sensors and heaters located inside of vacuum enclosure and near optical window
  - MOSA structure
    - T sensors monitoring the axial/transversal gradients



Lisa Pathfinder Magnetic Diagnostics system

Courtesy of M. Nofrarias (IEEC-CSIC)

Diagnostic system state-of-the-art

- *LPF heritage (TRL 9)*
- *LISA adaptation for T and magnetometer sensors to be done*

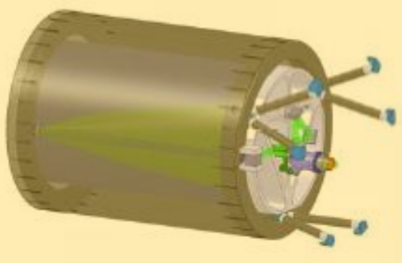
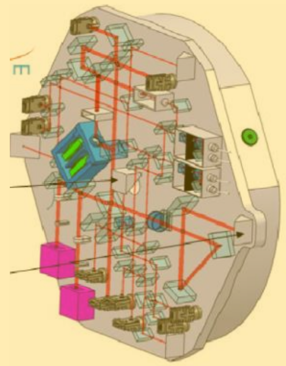
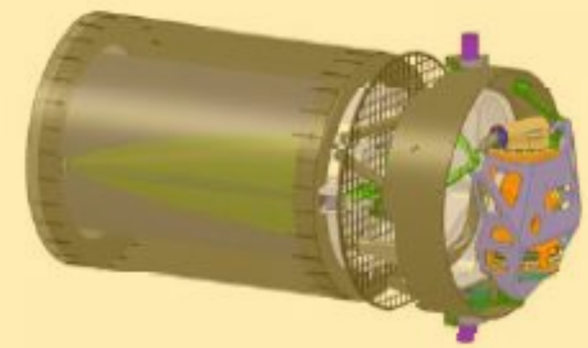
AIV/T

Assemblage, Integration, Verification and Test

Proposal of Consortium (France) AIV/T perimeter

Telescope + Optical Bench + Grav.Ref. Sensor = Moving Optical SubAssembly

(T) (OB) (GRS) (MOSA)

 +  +  = 

Consortium is responsible for delivering integrated/tested/validated MOSA

- Assembly and integration of Telescope + OB + GRS on MOSA mounting structure
  - Temperature Diagnostics elements mounted on units prior to delivery for MOSA integration

- Functional tests and performance validation
  - Phasemeter (PM) and Laser Assembly (LA) are required

MOSA Model Philosophy

- Elegant BreadBoard (EBB) [TBC]
  - Demonstrates mechanical/optical/electrical interfaces
  - Uses representative assemblies, but not flight

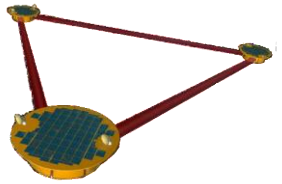
- Structural/Thermal Model (STM)
  - Validates mechanical interface, mechanical charge and thermal comportment
  - Uses dummy assemblies/units

- (Engineering) Qualification Model (E)QM
  - Validates MOSA conception and its AIV/T process
  - Uses flight representative assemblies/units
  - Submitted to qualification tests (i.e. vibrations)

- 6 Flight Models (FM)
  - Idem as (E)QM
  - Submitted to acceptance tests (verification of technical conformity)

Assumptions

- Consortium members & ESA partners (Prime or NASA) responsibility will delivery
  - Various subsystems models, from EBB, STM to FMs
    - Consortium: OB (UK), GRS (Italy), Diagnostics (Spain), Phasemeter (Germany)
    - ESA: Laser Assembly (NASA), Telescope (NASA), MOSA mounting structure (Prime)
  - For each subsystem:
    - Flight electrical/optical harness
      - Attached to MOSA connectors « bracket » at MOSA integration site
      - Test harness from bracket to GSE during performance validation
    - Unit test benches to the MOSA integrator with operators for training
    - Associated hardware simulators (e.g. SCOE: Special Check-Out Equipment)
    - Numerical models (behavioral and performance/noise models)
    - User manuals, interface definition, metrology and unit tests reports and data, etc.....



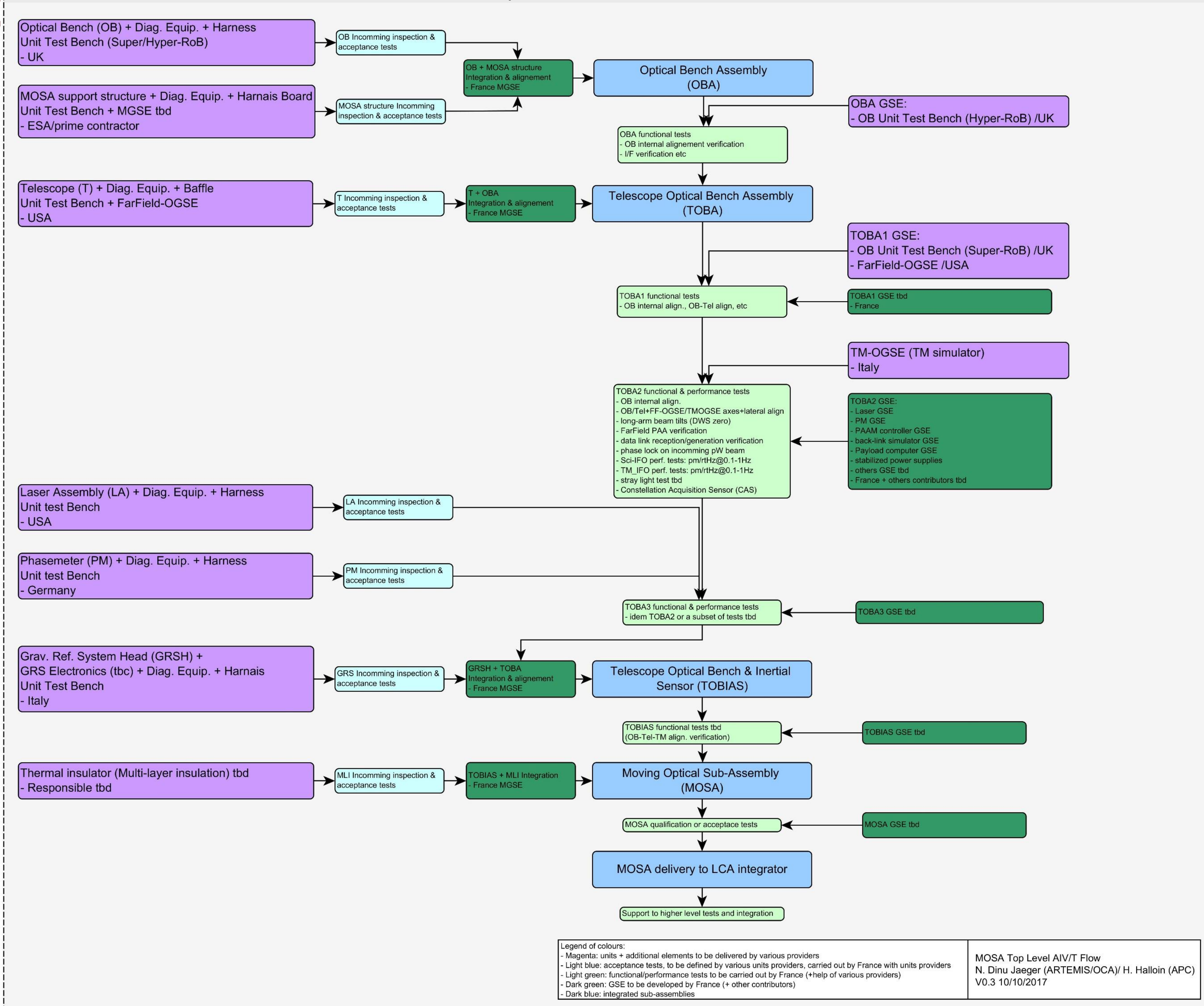
AIV/T Flow

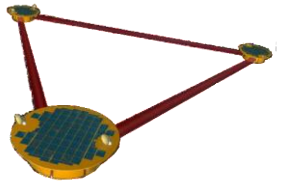
- **Main integration steps**

  0. Reception of all providers units at MOSA integration site
     - Acceptance tests (I/F verifications, command/control function tests etc.) to be defined by units providers together with MOSA integrator
  1. OB + MOSA structure = Optical Bench Assembly (OBA)
     - Integration and alignment checks
     - Functional tests
  2. OBA + Telescope = Telescope & Optical Bench Assembly (TOBA)
     - Integration and alignment checks
     - ***Functional and performance tests (Phasemeter and Laser Assembly are required)***
  3. TOBA + GRS Head = Telescope, Optical Bench & Inertial Sensor (TOBIAS)
     - Integration and alignment checks
  4. TOBIAS + other equip. (therm. shield) = Moving optical Sub-Assembly (MOSA)
     - Integration
     - Qualification or acceptance tests
  5. Delivery to P/L integrator
     - MOSA integrator gives support to higher level tests and integration

- **Proposed process**
  - 2 MOSAs in the integration facility at a time, at different integration & test stages

Top Level MOSA AIV/T flow

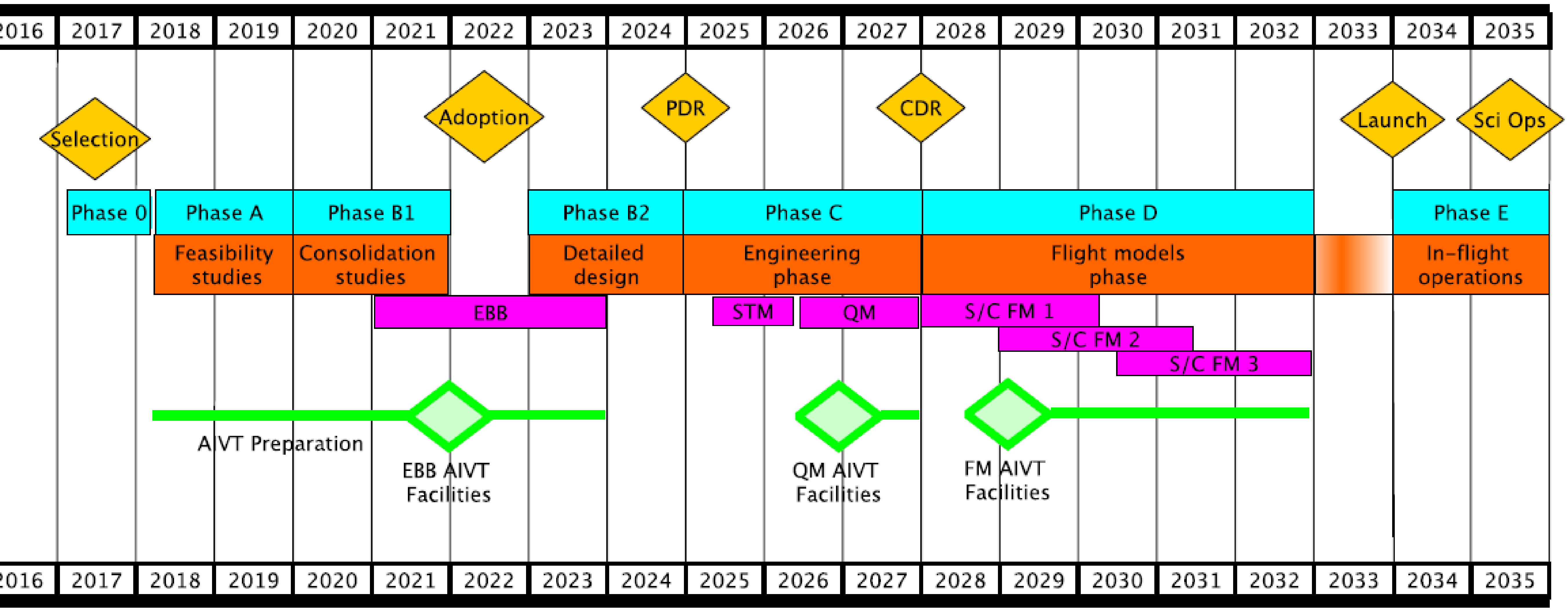




Short and long term AIV/T activities

- Short term (November 2017)
  - Redaction of an AIV/T chapter (our actual status of reflections), into the Payload Description Document (PDD) as a baseline document for Phase A
- Long term (during phase A, 2018-2019)
  - Identification of integration constraints at each integration step
    - Optical
    - Electrical
    - Mechanical
    - Thermal
  - Definition of functional and performance tests
    - What tests to do and why
  - Identification of GSE
    - Facilites
    - Equipment/ functionality needed to do each of those tests
    - What other units are needed
    - Where/when should/could they be done
  - MOSA AIV/T cost evaluation

Long term Planning



Phase A long term activities

- Already started, but still much more work is required
- Some examples in the next slides

Telescope Optical Bench Assembly (TOBA) (1)

- Integration constraints
  - TOBA size: $\Phi \sim 50$ cm, length ~ 100 cm (~250 cm if FF-OGSE & TM simulator are considered), mass ~ 27 kg
  - Alignment accuracy
    - Telescope w.r.t. OB: via a 2.24 mm pupil, real, located on the bench – critical alignment
    - ± 20 µm lateral, ± 100 µm longitudinal, ± 10 µrad
  - Thermal stability
    - 100 nK/√Hz
  - Contamination
    - Stray light
  - EM, vibrations
    - No specific constraint
- Tests on TOBA (list under progress)
  - Mechanical, optical & thermal I/F verification between OBA & Telescope
  - OB internal alignment using PD
    - Verify that internal alignment of all beams on the OB is still o.k. after Telescope integration
  - Heterodyne efficiency
  - Metrology axes alignments (PD/PD, PD/PAA, PD:CAS, PD/TEL etc.)
  - Calibration of PD signal w.r.t. TM movements
  - TX beam and PAAM (RX vs TX) characterization (offsets, calibrations, dynamic range, beam quality)
  - CAS/RX beam calibration, constellation acquisition
  - Contamination & stray level
  - Data link generation and reception (weak light, doppler etc.)
  - Science and TM IFO performance tests (measurements @ f>0.1 Hz, lower freq. by modeling)

Telescope Optical Bench Assembly (TOBA) (2)

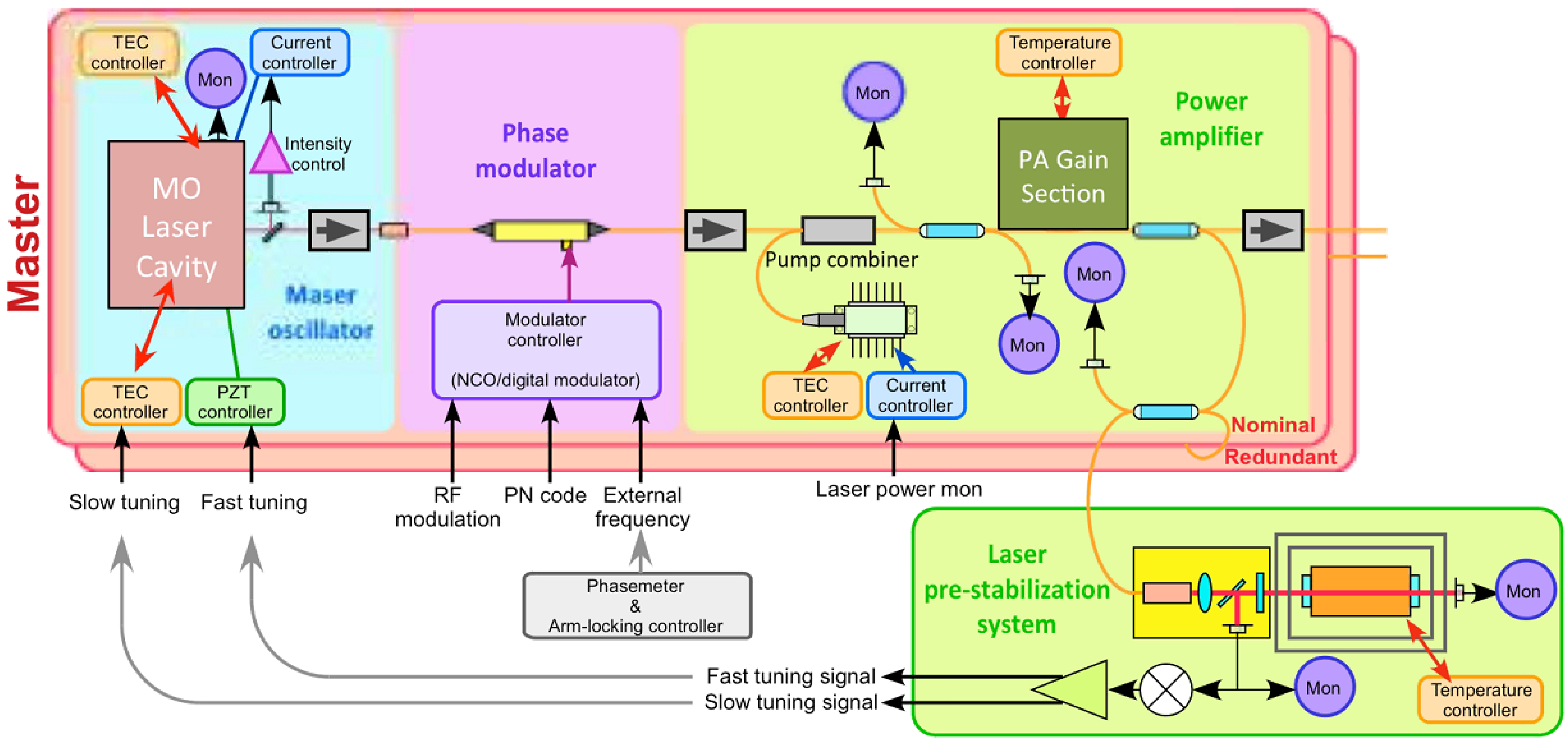
- Required GSE (list under progress)
  - Facilities [France]
    - Clean room: large surface (50-100 m^2); ISO 5 (class 100) over restricted area
    - µm precision 3D Coordination Measurement Machine (CMM)
    - MOSA MGSE
      - support TOBA/TOBIAS + FFOGSE during integration; isostatic mounts with different MOSA possible orientations
    - Vacuum chamber: $\Phi \sim 1$ m, 2-3 m long (it should accept also Telescope, FF-OGSE & GSE)
  - GSE for tests
    - Super RoB [UK]
      - Simple, battery powered, readout spot position from individual PD and check the alignment stability
      - Own laser system
    - FF-OGSE [NASA]
      - Simulates the characteristics (direction low intensity, truncated Gaussian beam shape, waveform quality etc.) of the laser beam coming from the far S/C and entering the telescope
      - Monitor the quality of the beam going out from the OB to the telescope
    - TM optical simulator [Italy]
      - Mirror with 3 tunable dof (1 translation and 2 rotations) simulating the TM movements
    - Data handling/ Payload computer SCOE [Spain?]
    - Backlink simulator [France?]
      - Simulates the exchange of the laser beams between the 2xOB of the same S/C
    - TX OGSE (included in Super RoB? or GSE laser source [France?] (FM for perf. & data link tests)
    - GSE phasemeter and Freq. Distribution [France?] (FM for perf. & data link tests)
    - Data logger [France]
    - …???

LISA AIV/T France

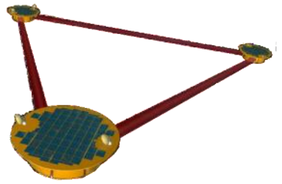
- Meeting at APC on 22/09/2017
- 10 participating laboratories showing their interest in participating at AIV/T MOSA activities
    - APC
    - ARTEMIS
    - 3 IRFU Départements
        - Département Astrophysique
        - Département électronique et computing (DEDIP)
        - Département d'Ingénierie des Systèmes (DIS)
    - LAM
    - LESIA
    - LMA
    - LPC-CAEN
    - SYRTE
- All interested laboratories are welcomed to join us

Additional slides

MOPA Functional Diagram – Master Laser

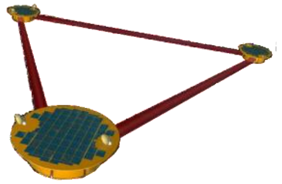


Courtesy of A. Yu (NASA GSFC), L. Mondin (ESA-ESTEC), B. Shortt (ESA-ESTEC)



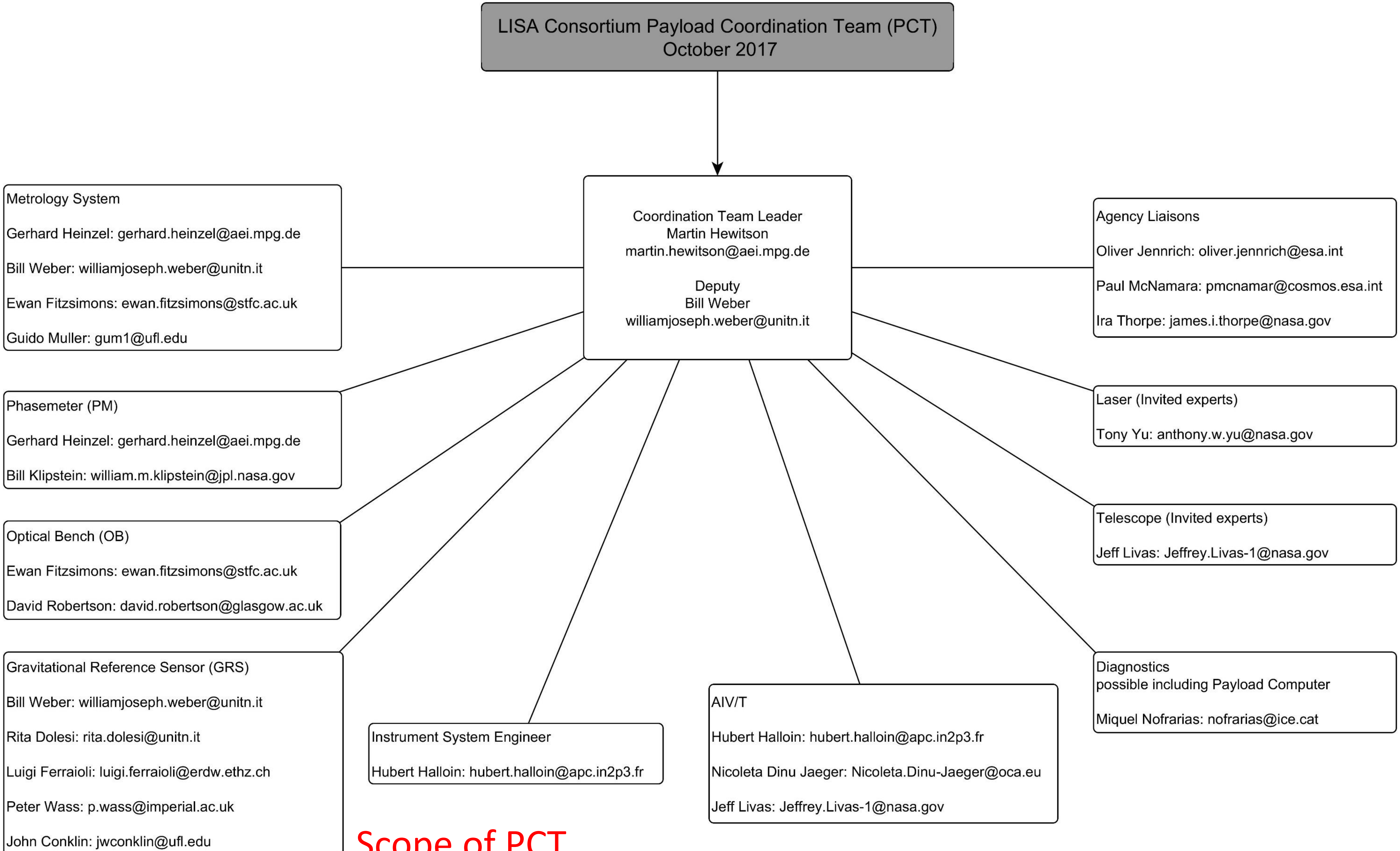
Optical Bench Assembly (OBA) (1)

- ## Integration constraints
  - OB size: Φ ~ 50 cm, thickness ~ 20 cm, mass ~ 17.5 kg
  - Alignment accuracy
    - ± 10-20 µm, ± 1 mrad [TBC]
  - Thermal stability
    - 100 nK/√Hz
  - Contamination
    - MOSA mounting structure material
    - Stray light
  - EM, vibrations
    - No specific constraints
- ## Tests on OBA
  - Mechanical & thermal I/F verification between OB and MOSA mounting structure
  - OB internal alignment using PD
    - Verify that internal alignment of all beams on the OB is still o.k. after OB integration on MOSA structure
  - Long term deformation tests [TBC]
  - Tests under vacuum or temperature variation [TBC]
  - ………….



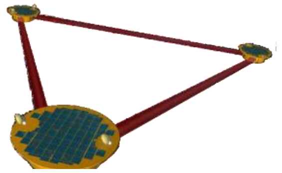
Optical Bench Assembly (OBA) (2)

- **Required GSE**
  - Facilities [France]
    - Clean room: large surface (50-100 m^2); ISO 5 (class 100) over restricted area
    - µm precision 3D Coordination Measurement Machine (CMM)
    - MOSA MGSE
      - support OBA/TOBA/TOBIAS during integration; isostatic mounts with different MOSA possible orientations
    - Vacuum chamber: $\Phi \sim 2$ m, 2-3 m long (it should accept also Telescope & FF-OGSE)
  - GSE for tests
    - Hyper RoB [UK]
      - Simple, battery powered, readout spot position from individual PD and check the alignment stability
      - Own laser system
      - Includes Optical Telescope Simulator
        - Simulating the laser beam entering from Tel to the OB and monitor and record the properties of the beam sent from OB to Telescope
    - Data logger [France]
    - ..???



Scope of PCT

- maintains instrument/mission scientific oversight in the consortium
- aids in interface definition between consortium provided equipment (CPE) and prime
- provide technical support to CPE industrial teams (where appropriate)
- provides support to system engineering teams, including ESA's system engineering office
- maintain oversight of technology development



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October 2017

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